New LCA Theses

Life Cycle Assessment to Evaluate the Environmental Impact of Arable Crop Production

PhD Thesis, Institute of Plant Nutrition, Department of Horticulture, University of Hanover, Germany

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Agriculture is expected to comply with sustainability principles, i.e. to be economically competitive, to produce high quality food in sufficient quantities at affordable prices, and to be environmentally benign. In order to evaluate the sustainability of agricultural production, it is necessary to have appropriate economic, social and environmental indicators in place. The main objective of this study is to develop indicators for the *environmental impact* of arable crop production. In a comprehensive environmental analysis of arable products and production systems, for example, it is important to find the most environmentally friendly production alternatives and to detect the environmental hotspots in the production systems. In order to evaluate the entire environmental burden associated with arable production, it is necessary to consider all important environmental impacts like nitrate leaching, ammonia volatilization or energy consumption. Furthermore, it is important to consider the impacts directly connected to the agricultural activities in the field together with those impacts, which are connected to the production and transportation of farm inputs like mineral fertilizers, seeds or machines.

The *Life Cycle Assessment* (LCA) methodology provides the framework for such an environmental analysis of products that takes into account the entire production system. Different LCA approaches have been developed based on this framework. However, since these models were primarily designed for industrial applications, they show some difficulties when applied to agricultural systems. Therefore, this study suggests adjustments of the LCA methodology to the specifics of arable crop production with a special focus on plant nutrition and, in particular, on fertilizer use.

In the following, the main results of the thesis are summarized briefly:

- Structured methods for the estimation of *diffuse, on-field nitrogen emissions* (ammonia, nitrous oxide, nitrate) were proposed in order to enable reasonable estimates of these highly variable emissions as an input to LCA studies. These estimation methods consider important soil, climate and management (e.g. plant nutrition) parameters.
- In contrast to other approaches, this study suggests treating the *consumption of abiotic resources*, which are not substitutable by one another, as separate environmental problems. A final aggregation of non-equivalent resources like phosphate rock and fossil fuels into a summarizing resource depletion indicator was found to be only possible after an explicit weighting procedure, which was developed in this study.
- Arable farming uses huge quantities of land for crop production. An assessment of the environmental impacts of *land use* in LCA has to include two dimensions: (a) the size of an area used for a certain period of time and (b) the potential of a specific land use type to degrade the naturalness of the area under use. Whereas the first aspect can be directly expressed as a physical quantity, the latter aspect needs an appropriate indicator. The Hemeroby concept provides such an indicator, since Hemeroby is defined as a measure for the human influence on ecosystems. It describes the level of naturalness of different land use types (e.g. urban area or extensive pasture) according to their deviation from a natural reference situation. This study employs the Hemeroby concept in order to assess the impacts of different land use types within LCA.
- A procedure was developed to aggregate the different environmental effects that are relevant to arable production systems (abiotic resource depletion, land use, climate change, acidification, eutrophication). As a result, two *summarizing environmental indicators* can be calculated: (a) for abiotic resources and (b) for impacts on ecosystems and human health. The weighting is based on the 'distance-to-target principle'. This study suggests internationally agreed environmental targets to be employed in this procedure because they represent a consensus of science, economy and society.
- After these methodological developments, the method was tested in a *case study*. In this case study, the environmental impact of different nitrogen (N) fertilizing intensities in European winter wheat production was analyzed. The case study revealed that the aggregated environmental impact per ton of wheat grain increases dramatically at N rates exceeding the crop demand and at zero N fertilization. In the first case, aquatic eutrophication was the major problem, whereas this was land use in the latter case. A reduced N application below the economic optimum N rate leads only to small improvements of the environmental impact of arable crop production. At economic optimum N fertilization, aquatic eutrophication contributed most to the aggregated indicator; while terrestrial eutrophication, acidification, climate change and land use show similar contributions to the aggregated value.